Forbes (W. S.) Doctor John B Roberts
With the compliments of
Dr Forbes

Extracted from the American Journal of the Medical Sciences for July, 1880.

THE DIAPHRAGM: A PROTECTOR OF THE HEART AND CARDIAC VESSELS; ITS INFLUENCE ON THE ORGANS OF CIRCULATION.

A PAPER READ BEFORE THE COLLEGE OF PHYSICIANS OF PHILADELPHIA, MAY 8.

BY

W. S. FORBES, M. D.,

FELLOW OF THE COLLEGE, SENIOR SURGEON TO THE EPISCOPAL HOSPITAL, AND DEMONSTRATOR OF ANATOMY IN JEFFERSON MEDICAL COLLEGE, PHILADELPHIA.

[Extracted from the American Journal of the Medical Sciences for July, 1880.]

THE DIAPHRAGM: A PROTECTOR OF THE HEART AND CARDIAC VESSELS; ITS INFLUENCE ON THE ORGANS OF CIRCULATION.

A PAPER READ BEFORE THE COLLEGE OF PHYSICIANS OF PHILADELPHIA, MAY 8.

By W. S. FORBES, M.D.,
FELLOW OF THE COLLEGE, SENIOR SURGEON TO THE EPISCOPAL HOSPITAL, AND DEMONSTRATOR OF ANATOMY IN JEFFERSON MEDICAL COLLEGE, PHILADELPHIA.

On opening the thorax and abdomen in living cats and dogs, while under the influence of ether, for the purpose of examining the motions of the heart, I have observed that the vena cava inferior opening through the pericardium and into the right auricle is held in a fixed relation to the vertebral column. Observing this fact I was induced to examine the vena cava inferior opening in the diaphragm, and its relation to the vertebral column in the human body.

I find that the vena cava inferior opening in the diaphragm of man is stationary, and holds a constant and fixed relation to the inferior part of the right antero-lateral margin of the ninth dorsal vertebra, and that it is not moved upwards nor downwards from its position by the surrounding organs in the performance of their function.

The diaphragm is a thin musculo-tendinous partition placed obliquely between the abdominal and thoracic cavities. It forms the floor of the thorax and the roof of the abdomen.

It is elliptical in shape, its largest diameter being from side to side. It consists of muscular fibres which arch upwards as they converge from the circumference of the abdominal cavity to the marginal under surface of a tendinous structure in the centre. The muscular fibres arise, in front, by two short muscular slips, one on either side of the middle line, from the ensiform cartilage of the sternum; those placed more laterally are attached to the inner surface of the cartilages and bony portions of the seven inferior ribs, interdigitating with the transversalis abdominis; behind they are attached to two aponeurotic arches, named the ligamentum arctuatum internum and externum; and on either side of the middle line posteriorly they are attached, by means of two thick tendinous crura, to the bodies and interposed fibro-cartilages of the upper lumbar vertebra; the one on the right side to the first, second, and third, and the one on the left side to the second and third lumbar vertebræ. The tendons of both these crura curve forwards and upwards and unite in forming an arch over

the aorta, which is placed between the crura and in front of the vertebræ and under the tendinous arch. Muscular fibres spring from the anterior aspect of these tendinous crura in two thick bundles and diverge as they pass upwards to the aponeurotic centre. They are called the pillars of the diaphragm. The innermost muscular fibres of each crus pass upwards and inwards and thus decussate with each other, those of the right side usually lying anterior to those of the left side, and curving upwards they limit an opening for the transmission of the œsophagus before ending in the central tendon.

The ligamentum arctuatum internum is a fibrous band which extends from the body to the transverse process of the first lumbar vertebra, and arches over the upper part of the psoas muscle.

The ligamentum arctuatum externum extends outwards from the transverse process of the first lumbar vertebra to the last rib, arching over the front of the quadratus lumborum. From both ligamenta arctuata diaphragmatic muscular fibres take their origin, and are directed upwards to the posterior part of the tendinous centre of the organ.

The two short muscular fibres coming from the ensiform cartilage form a narrow slip on each side of which there occurs an interval, in which the lining membranes of the thorax and abdomen are separated only by a small quantity of loose connective tissue. Consequently we find here a weak point through which diaphragmatic hernia may take place.

The central tendon or cordiform tendon is a strong aponeurosis forming the central part of the diaphragm. It is elongated from side to side, and consists of three leaflets, partly separated by indentations; the right leaflet is the largest, the middle one is placed anteriorly, and the left which is elongated and narrow is the smallest of the three.

The central tendon is surrounded on every side by the muscular portion of the diaphragm, the fibres of which are directly continuous with those of the tendon.

There are in the diaphragm three large openings for the passage respectively of the aorta, the œsophagus, and the inferior vena cava; besides, some smaller holes or fissures which are less regular.

The opening for the aorta (hiatus aorticus) is not a complete foramen in the diaphragm, being an osseo-aponeurotic opening formed by the tendinous arch thrown across the front of the bodies of the vertebræ from the crus on one side to that of the other. It is, consequently, behind the diaphragm. It transmits the aorta, vena azygos major, the thoracic duct, and, occasionally, the left sympathetic nerve. It is the most inferior of the three openings of the diaphragm.

The œsophageal foramen is placed above, and, at the same time, anterior, and a little to the left of the aortic opening. It is elliptical in form muscular in structure, and bounded by the muscular fibres coming from the two crura. Its anterior margin is occasionally tendinous. It trans mits the œsophagus and the pneumogastric nerves.

The foramen for the ascending vena cava is the highest of the openings of the diaphragm. It is more or less quadrilateral in form, tendinous in structure, and placed posteriorly at the junction of the right and middle leaflets of the central tendon. Its margins are bounded by four bundles of tendinous fibres which meet nearly at right angles.

The right crus transmits the sympathetic and the greater and lesser splanchnic nerves of the right side ; the left crus transmits the greater and lesser splanchnic nerves of the left side and the vena azygos minor. The serous membranes of the diaphragm are four in number, three lining its upper or thoracic surface and one its abdominal surface. Those on its upper part are the pleura on either side, and the serous layer of the pericardium, which covers the middle portion of the tendinous centre.

The serous membrane which covers the under surface is a portion of the general peritoneal membrane of the abdominal cavity.

The diaphragm is arched, being convex towards the thorax and concave towards the abdomen. Its left portion is lower than the right by about three-quarters of an inch. It supports the base of the left lung and covers the great end of the stomach, the spleen, and the left kidney.

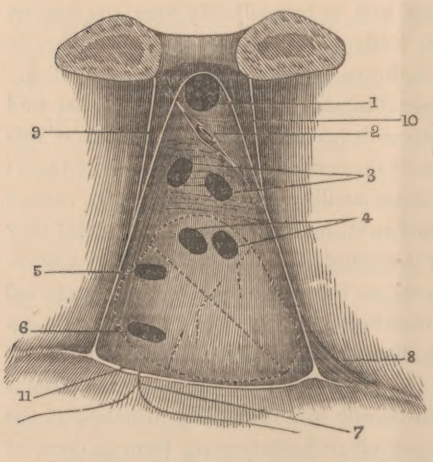
The right portion forms a complete arch from before backwards. It supports the base of the right lung, and is immediately over the convex surface of the liver. The central leaflet supports the heart, is higher in front at the sternum and behind at the vertebræ than the lateral leaflets.

The pericardium is a conical membranous sac in which the heart and commencement of the great bloodvessels are contained. The base of this sac is attached to the upper surface of the central tendon of the diaphragm ; and on its anterior left side the muscular fibres of the diaphragm ascend on the pericardium and are attached to it, and in the new-born child play an important part to be hereafter described. The pericardium is a fibro-serous sac consisting of two layers, an internal serous and an external fibrous membrane. The serous membrane invests the heart, and is reflected on the inner surface of the fibrous membrane and over the upper surface of the central tendon of the diaphragm embraced by the fibrous membrane. The fibrous membrane firmly and intimately attached to the central tendon of the diaphragm ascends and converging forms a cone, at the apex of which the great bloodvessels issuing from and going to the heart are supported in their relative position by means of transverse and oblique bands of fibrous tissue which are continued on the walls of these vessels in the form of tubular prolongations, and which are gradually lost upon their external coat ; the largest and strongest of these tubular prolongations is the one inclosing the aorta.

From the right and left external lateral surfaces of the fibrous membrane of the pericardium, and from near the apex of the pericardial cone, prolongations of the fibrous tissues continue upwards as strong bands, forming the antero-lateral parietes of the superior portion of the posterior mediastinal space and reaching the inner aspect of the first rib on each side, and

coalescing with the thoracic fascia of Sir Astley Cooper, are held in a fixed position by this fascia which is stretched across the apex of the thoracic cone. These two strong bands continuous with the lateral portion of the pericardium thus form fibrous planes reaching from each side of the central tendon of the diaphragm to the bony apex of the thoracic cone. They form what may be called the superior tendinous crura of the diaphragm, upon the sides of which the phrenic nerves descend to reach the diaphragm; and by means of transverse and oblique bands of fibrous tissue connecting these tendinous crura together at and above the pericardial cone, a strong fibrous scaffolding is formed on which the great cardiac vessels are supported and protected. These superior tendinous crura of the diaphragm are inextensible. Each crus of the diaphragm is fixed above to the bony apex of the thoracic cone, and by fibrous connection, to the thoracic fascia of Sir Astley Cooper, which is stretched across the thoracic apex. The thoracic fascia of Cooper is supported above by the deep cervical fascia, which is strongly attached to the processes of the cervical vertebræ and to the stylo-maxillary ligament on each side of the base of the skull.

Fig. 1.



The above wood-cut represents a vertical section of the pericardium and diaphragm. The heart and the serous pericardium are removed showing the openings for the lodgment in the fibrous scaffolding: 1, aorta; 2, ductus arteriosus compressed in its elliptical opening, divided and turned up; 3, right and left pulmonary arteries; 4, pulmonary veins; 5, superior vena cava; 6, inferior vena cava opening into diaphragm. 7. Suspensory ligament of liver, the section is at a point midway between the cava opening in the diaphragm and the abdominal wall. 8, muscular fibres ascending on anterior left aspect of pericardium; 9 and 10, fibrous planes ascending laterally from pericardium to reach the apex of bony thoracic cone. 11, cordiform or tendinous portion of diaphragm below the heart.

"The thoracic fascia," writes Sir Astley Cooper, in his work on the Anatomy of the Thymus Gland, "performs three important offices: 1st. It forms the upper boundary of the chest, as the diaphragm does the lower. 2d. It steadily preserves the relative situation of the parts which enter and quit the thoracic opening. 3d. It attaches and supports the heart in its situation through the medium of its connection with the aorta and larger vessels which are placed at its curvature."

In continuing downwards and connecting itself with the lateral and superior parts of the pericardium the thoracic fascia forms on either side a membranous continuity with the diaphragm, and in connection with that organ performs an important function on the circulatory apparatus.

The muscular fibres at the circumference of the diaphragm

contracting, and the pericardial portion of the central tendon being fixed on a plane with the lower part of the body of the ninth dorsal vertebra, which cannot descend on account of the superior crura and the fibrous scaffolding which I have pointed out, the following parts are acted upon: the aortic arch of the diaphragm is drawn forward and made more free; the muscular œsophageal opening is contracted; the tendinous vena cava opening is held open to its fullest extent. Continuing to contract, the muscular circumference of the diaphragm now exerts its force on the pericardium and the superior crura or lateral fibrous planes, and upon the fibrous scaffolding between these crura, thus holding it open and tense, open to allow the flow of blood to and from the heart, and tense in order to protect the heart and bloodvessels, which if not protected would have their function greatly impaired by pressure on the part of the now expanding lungs. These functions of the diaphragm on the organs of circulation take place though the lateral portions of the diaphragm may not be permitted to descend on account of the contraction of the stronger abdominal muscles or from artificial restraint of the abdominal walls. The muscular diaphragm will contract on its own planes and still perform its functions for the benefit of the vascular apparatus, though it may be prevented from descending, thus extending the vertical area of the respiratory organs.

The right superior fibrous crus of the diaphragm is vertical in its direction. It is at the foot of this crus, and on its inner aspect, that we find the vena cava opening of the diaphragm. It is the right superior inextensible crus which holds up under the concave surface of the diaphragm the entire weight of the liver, an organ in the adult of four pounds avoirdupois. The falciform or suspension ligament of the liver is formed by two folds of the peritoneum reflected from each inferior lateral margin of the fibrous vena cava opening in the diaphragm down to the lateral margins of the vena cava fissure in the liver; the two folds meeting in front of the vena cava form the apex or point of the falciform ligament, which here is very short, holding the vena cava fissure in the liver close up to the vena cava opening in the diaphragm.

At this point, the apex of the falciform ligament, behind which the vena cava issues from its fissure in the liver to ascend to its diaphragmatic opening, the liver cannot descend. The base or anterior aspect of the falciform ligament is broad, and permits the anterior margin of the liver to fall and then to be elevated to and behind the ensiform cartilage by the action of the abdominal muscles. The lateral wings of the diaphragm and the muscular parietes of the abdomen in contracting and relaxing make lateral pressure upon the liver, and thus in a most positive manner advance the venous circulation and the flow of bile in the parenchyma of the liver, for the walls of the vessels in which these fluids are lodged have no muscular tissue.

In the very young fœtus the thorax and abdomen form one cavity as

in birds, reptiles, and fishes. The diaphragm in the fœtus is developed by a process of growth from the circumference to the centre, and when developed is in a passive state until birth. In the neonatus the muscular diaphragm is called into immediate action, and in contracting performs at once a most important function in compressing the ductus arteriosus, thereby diverting the current of blood into the two branches of the pulmonary artery, which go respectively to the right and left lung. The peculiarities in the arterial system of the fœtus are the communication between the internal iliac arteries and the placenta by means of the umbilical arteries, and the communication between the pulmonary artery and upper part of the descending portion of the arch of the aorta by means of the ductus arteriosus. In the fœtus and up to the birth of the neonatus the right and left branches of the pulmonary artery are, relative to the main pulmonary artery, very small, and come off from the posterior aspect of the artery while the ductus arteriosus is in front of them nearer the sternum, and is much larger, and is in fact the continuation of the main pulmonary artery to the arch of the aorta, into which it opens just below the origin of the left subclavian artery, and so conducts the current of blood from the right ventricle into the descending aorta.

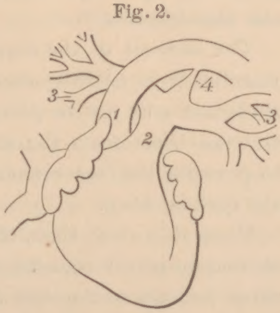
The ductus arteriosus is lodged in an elliptical opening in the fibrous scaffolding beneath the descending portion of the arch of the aorta, which opening extends obliquely from above downwards and forwards and to the left, going in front of the descending aorta behind the "vestigial fold" of Marshall (which is formed by a duplication of the serous membrane between the pulmonary artery and the subjacent pulmonary vein), and above the left branch of the pulmonary artery. The tendinous fibres forming the margins of this elliptical opening embrace the ductus arteriosus and are connected to its external coat by connective tissue; they extend from the inner aspect of the superior posterior margin of the right fibrous plane or crus, downwards and forwards and to the left to become attached anteriorly and below to the inner surface of the left fibrous plane or crus, and the muscular fibres of the diaphragm contracting at the first inspiration at birth the tendinous fibres of the elliptical opening are made to compress the ductus arteriosus and eventually close it. Especially is this compression made by the contraction of those muscular fibres of the diaphragm which ascend upon and are attached to the anterior left aspect of the pericardium. The alternate pressure and relaxation made on the ductus arteriosus by the contraction of that part of the muscular diaphragm referred to is exactly similar to the procedure we now adopt in closing by pressure, sufficient for the formation of a clot, the main artery in cases of aneurismal tumours, and the effect in both instances is exactly the same; in cases of aneurismal tumours while the clot is being formed the collateral circulation is being established by the distension and permanent enlargement of the collateral branches on the cardiac side of the point of pressure, though

these branches are lodged in far denser tissue than the undistended fœtal lung.

When the ductus arteriosus is being compressed by the margins of the fibrous opening in the fibrous scaffolding in which it is lodged, drawn upon by the muscular tissue alluded to, and while the clot is being formed, the right and left pulmonary branches going to the lungs are being distended and permanently enlarged until their united capacity is equal to the entire volume of blood in the main pulmonary stem, and thus the collateral circulation is eventually established with the aorta by means of the appropriate organs. The ductus arteriosus in the mean time is filled with the clot becoming organized, which permanently closes it. We may believe that in the case of the compressed ductus arteriosus, the collateral circulation with the aorta would take place though the lungs did not expand, just as the collateral circulation would be established on ligating any other artery, one in the extremities for instance. In short the expansion of the lungs, *per se*, has nothing to do with the closure of the ductus arteriosus. The expansion of the lungs is for the aëration of the blood, and they are made to expand by muscles of respiration independent of the descent of the diaphragm, and we may believe the closure of the ductus arteriosus and the collateral circulation with the aorta would be established by reason of the contraction of the diaphragm, though this diaphragm were restrained from descending.

The line of pressure exerted on the ductus arteriosus is nearer to the aorta than to the two branches of the pulmonary artery. The clot soon becomes firm and the closure of the duct is made complete by the eighth day.

Fig. 2.



Heart of infant showing the mode of disappearance of the ductus arteriosus after birth. 1. Aorta. 2. Pulmonary artery. 3, 3. Pulmonary branches. 4. Ductus arteriosus becoming obliterated. (After Dalton.)

The further influence of the muscular lamina, attached to the anterior left aspect of the pericardium on the fibrous surrounding of the ductus arteriosus, is observed in the future development of the branches of the pulmonary artery, for at maturity or in the adult the fibrous cord, the remains of the former ductus arteriosus, is found reaching from the aorta to near the root of the left branch of the pulmonary artery, the muscular lamina on the pericardium having drawn it in that direction away from its former situation in a line with the long axis of the main pulmonary artery. Sometimes, indeed, the fibrous cord is entirely removed by absorption following this pressure, and no vestige of the former organ is to be seen.

Such is the function performed by the contraction of the muscular diaphragm on the ductus arteriosus and on the pulmonary circulation of the new-born child. "*Post cor facile princeps.*"

When the lateral wings of the diaphragm, contracting, are permitted to descend, then and not until then do they tend to form a vacuum in the thorax, and thus assist to promote the venous circulation in the thorax and consequently in the whole venous system in the body. The first and most continuous effect of the contraction of the diaphragm, whether it is permitted to descend or not, is for the protection of the central circulatory apparatus, and the promotion of the circulation of the blood. If the diaphragm is injured the result of that injury is experienced first by the heart. This fact is verified in the clinical histories of injuries of the phrenic nerve and the diaphragm. Thus, it is well illustrated in the case recorded by Mr. Pollock in Holmes's *System of Surgery*, vol. ii. p. 650, as being under the care of Mr. Cæsar Hawkins, in St. George's Hospital. If one side of the diaphragm is lacerated, or if there is unilateral paralysis of the diaphragm, the heart is pushed over to the opposite side of the thorax by the expanding lung, the lateral fibrous scaffolding being no longer supported on the side of the paralysis. In bilateral paralysis the heart is pushed backwards by the lungs advancing in front of it, and during inspiration the epigastrium and hypochondria are depressed, the heart, with the pericardium and its attachments to the diaphragm in front and at the base of the thoracic cone, being carried backwards by lung pressure in front; the anterior and lateral attachment of the diaphragm cause the depression of the epigastrium and hypochondria, phenomena so characteristic of bilateral paralysis. Duchenne informs us that if in these cases the phrenic nerves be galvanized the diaphragm acts again with proper strength, and during inspiration the thoracic and abdominal walls rise simultaneously.

The descent of the diaphragm is not necessary to respiration, this is manifest from ordinary observation; but the contraction of the diaphragm, though it may not be permitted to descend, is necessary in order to protect the heart from the movement of surrounding viscera, and in order to promote the free circulation of the blood through the vessels forming the cardiac roots.

From this view, then, of the anatomy and functions of the diaphragm, this organ may be classed rather as an appendage to the circulatory apparatus, and not as the chief agent of respiration as heretofore believed. The natural history of the diaphragm would tend to confirm this view. It is found first in mammals. These animals require a diaphragm to protect the central organ of circulation from the encroachment of the neighbouring lungs and abdominal viscera, and by its contracting to act in promoting as well as protecting the functions of the heart. In birds and in turtles and tortoises, such an organ as the diaphragm is not required. In these animals the thoracic and abdominal viscera are in one and the same cavity, but the movement of the lungs is limited by means of pleural attachments, and the heart and its great vessels are protected by peritoneal folds which

form restrictions by being attached to distant points of a rather fixed bony framework. In them the diaphragm is not found, as it is not needed.

In the foregoing remarks we have endeavoured to demonstrate that—

1st. The vena cava inferior opening, the highest point in the central tendon of the human diaphragm, holds a constant and fixed relation to the right anterior inferior border of the ninth dorsal vertebra.

2d. That portion of the central tendon embraced by the base of the fibrous pericardium is prevented from descending in inspiration by the superior tendinous crura of the diaphragm which are formed by the lateral parts of the fibrous pericardium ascending on either side in two planes to be attached to the apex of the bony thoracic cone and through the deep cervical fascia to the processes of the cervical vertebræ, and to each stylo-maxillary ligament.

3d. These superior tendinous crura of the diaphragm are connected together by transverse and oblique fibrous bands, thus forming a fibrous scaffolding for the support and protection of the heart and the great cardiac vessels.

4th. The opening in the fibrous scaffolding for the lodgment of the ductus arteriosus in fœtal life is closed by the contraction of the muscular fibres ascending on the fibrous pericardium from the anterior left side of the diaphragm in the neonatus.

5th. The blood in the pulmonary artery of the neonatus is *forced* into and through the right and left pulmonary arteries and into the lungs by the contraction of the right ventricle, which at this moment has its walls as thick as those of the left ventricle, and by the elasticity of the pulmonary artery, and is not *drawn* into the pulmonary arterial branches and into the lungs by the expansion of the lungs.

6th. The superior fibrous crura and the fibrous scaffolding between them are made tense and open for the lodgment and for the protection of the heart and its great vessels, and for the promotion of the circulation of the blood through them by the contraction of the muscular diaphragm, independent of the descent of its lateral wings, though in the descent of the lateral wings of the diaphragm the vertical area of the thorax is extended.

7th. In the contraction of the muscular diaphragm its descent is not necessary as it contracts on its own planes, which may be supported by the contraction of the stronger abdominal muscles.

8th. The diaphragm is rather an appendage of the circulatory apparatus, and not "essentially the chief agent in respiration."

1409 Locust Street, Philadelphia.